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IRRIGATION POTENTIALITIES IN ARKANSAS

by Paul H. Berg, A.M. ASCE

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IRRIGATION POTENTIALITIES IN ARKANSAS

Paul H. Berg,[1] A.M. ASCE

SYNOPSIS

The rainfall in Arkansas, although abundant when measured annually, is insufficient to meet the crop requirements during the growing season. Irrigation to supplement the growing season rainfall deficiency would result in an increased production of crops. This paper discusses some of the problems which may be encountered with the development of irrigation in Arkansas.

INTRODUCTION

In 1950 the population of the United States was approximately 150 million. It is conservatively estimated that by 1975 this population will have increased to 190 million; and by the year 2000, the population will total 215 million. This increase in population will cause an ever increasing demand for food and fiber. Reduced to simpler terms this means that, for every four people that are fed in the nation today, five will have to be fed by 1975, and six will have to be fed by 2000. In addition to the increasing need due to increasing population, it is anticipated that the dietary standards of the people of the nation will continue to improve in future years as in the past.

In past decades the increasing need for production has been met by (1) new farmland brought under cultivation, (2) conversion of land from production of feed for draft animals, (3) increased use of fertilizer, (4) improved farming methods, (5) improved varieties of crops, (6) elimination of drouth by irrigation, and (7) importation from other countries. Further increases in production by the first two methods will be extremely limited. This paper deals with only one of the remaining items--elimination of drouth by irrigation.

The information contained in this paper was largely obtained and compiled as a result of a study of the problem in the State of Arkansas by the Bureau of Reclamation. The investigation was a part of the work carried on under the Flood Control Act of 1950 for a cooperative inter-agency investigation of the Arkansas, White, and Red River basins. Arkansas lies wholly within the humid region of the United States and there is every reason to believe the results of this investigation are typical of those which might be obtained in other humid areas. Every effort was made to determine (1) the need for additional water to supplement natural precipitation in this humid region, (2) the probable increase in crop value which could be expected, and (3) the construction and other problems which may be encountered in development of potentially irrigable areas. Plate 3 shows the areas in Arkansas which were studied.

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1. AWR Basins Planning Engineer, Bureau of Reclamation, Tulsa, Oklahoma.

Need for Additional Water

In general, the need for irrigation is indicated by (1) the deficiency in natural precipitation required to provide the water consumptively used by crops and (2) the increase in crop production which will result from supplying this deficiency by irrigation. These subjects have received comparatively little study in the humid regions because the economic pressures for maximum crop production have not yet been great either locally or nationally.

The climate of Arkansas is quite similar to that of other southern states. Summers are long and warm with temperatures occasionally going above 100 degrees and with the humidity staying at about 70 percent. Winters are mild with temperatures rarely going below zero. The average annual rainfall approaches 50 inches and varies from a minimum of 24 inches to a maximum of 84 inches. Unlike the semi-arid regions of the West, about 70 percent of the rainfall occurs during the winter and spring months; consequently, the summer or growing season precipitation does not differ materially from that of the semi-arid regions. The average growing season is quite long, being 247 days at Fayetteville in the northwestern part of Arkansas, 274 days at Newport in the east-central part, and 308 days at Portland in the southwestern part. The growing season generally starts in the first half of March and ends in the last half of November.

In the studies which were made in Arkansas, one comparatively specialized problem arose in connection with the determination of the need for water for rice production. Rice can only be grown in standing water with a controlled depth of from 4 to 7 inches. Water is applied to the rice fields at the beginning of the season; it is later drained off, and the fields are allowed to dry out for about two weeks. Water is then reapplied and maintained at the above mentioned depth for the remainder of the growing period. The need is thereby based upon factors other than the consumptive use of the plants. A quantative evaluation of the need was made from studies of pumping records where pumps were used as the sole source of irrigation water for relatively large areas of rice cultivation over long periods of time.

In the case of general crops as grown in Arkansas and elsewhere throughout the nation, the need for water is based upon the consumptive use of the particular crops in question. It has long been recognized that throughout the entire nation crop production is frequently restricted by the failure of rains to fall in the proper amounts at the proper time. This is particularly true in Arkansas where there are frequent periods of apparent drouth, with one or more short periods occurring each year. A drouth period is defined as any period of 20 days or longer each 10 days of which has less than one-half inch of rainfall.

Figure 1 shows the apparent drouths which have occurred at Newport, Arkansas, from 1931 to 1952, inclusive.

As a first step in the determination of the need for additional water, it is necessary to determine what amount and distribution of water the various crops need for optimum production. It is then necessary to determine what portion of that requirement is supplied by precipitation. The remainder, if any, is the requirement for additional water. Consumptive use and effective precipitation studies were made, using climatological data from stations at Fayetteville, Newport, and Portland, Arkansas. These studies led to a determination of the deficiency in rainfall required to meet consumptive use requirements. Annual gross consumptive use of water was estimated by the

Lowry-Johnson method,[2] and it was found to average 31.8 inches in the northwestern portion of the state, 34.9 inches in the east-central portion, and 37.2 inches in the southeastern portion. The annual consumptive use was distributed by months according to monthly effective heat and was adjusted to meet the probable cropping pattern. Effective precipitation studies were made using climatological data from the same stations that were selected for the preparation of consumptive use studies. Experience has demonstrated that not all precipitation which falls during the growing season is effective in meeting the consumptive use requirements of crops. It has further been found that as rainfall increases, the percentage of that rainfall which is effective in meeting consumptive use requirements decreases. On the basis of experience in other areas, a curve was developed for estimating the monthly effective precipitation from the recorded actual precipitation. Effective precipitation was deducted from the monthly gross consumptive use to determine the deficiency in moisture. When the effective precipitation exceeded the consumptive use, the excess was considered to accumulate month to month so long as the accumulated carry over did not exceed the estimated optimum soil moisture capacity. Table 1 shows the monthly distribution of the average gross consumptive use at Newport, Arkansas, and the deficiency in moisture for the growing season months of March through November for a dry year (1952), a wet year (1951), and the twenty-two year average (1931 to 1952, inclusive).

Many of the apparent drouth periods shown in Figure 1 occur in May and June, whereas Table 1 shows very little deficiency in moisture for these months. This is readily explained by the fact that effective precipitation during previous months has exceeded the consumptive use and there has been a substantial carry over of soil moisture. A careful review of Table 1 leads to the conclusion that the dry year of 1952 had water deficiency characteristics somewhat different from the average. Water deficiency may be expected in August and September of every year, whereas, such deficiencies do not always occur in July. The soil moisture carry over from June frequently sustains crops through a July drouth. The results of the consumptive use and effective precipitation studies show that some additional water is required every year to meet the full crop requirement.

Increase in Crop Value

Experience in Arkansas since 1904 has shown that the production of rice will yield greater income per acre than will any other crop now grown in quantity in that state. Rice can be grown only with irrigation. In 1950 rice was harvested from 411,000 acres of the approximately 1,386,000 acres in irrigated farms.[3] The reconnaissance land classification by the Bureau of Reclamation shows 2,190,000 acres suitable for rice production. Of this acreage, about one-third, or 730,000 acres, could produce rice each year. This is an increase of 78 percent over the acreage harvested in 1950. It is commonly recognized that there would be an increase in income by the irrigation of more rice; provided, the nation as a whole will consume the increased rice production. A study of rice production in the United States and a forecast of future demand for rice was completed in 1953. This study indicates that a

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2. A.S.C.E. Transactions, Vol. 107. 1942, Page 1243
3. U. S. Census

total of 2,109,000 acres of rice should be harvested in the United States in the year 2010 in order to meet the estimated national requirement of 106,600,000 bushels. The development of most of the rice type land in Arkansas currently unused, as well as efficient use of the land resources in the other rice producing states, would be necessary to meet the forecast requirements. These production requirements exclude the effect of even partial achievement of the Rice Millers' goal of stimulating civilian domestic rice consumption above 5.5 pounds per capita. Any significant success in stimulating domestic use would, under normal trend conditions, utilize all the land of the Nation suited to rice production and decreasing quantities would be available for export.

Irrigation is not generally practiced to raise crops such as cotton, corn, oats, lespedeza, and soybeans; nor is it practiced in the northwestern part of the state where grapes, fruits, and fresh vegetables are raised. Land that is suitable for rice cultivation is used for rice one year, is irrigated (when water is available) for general crop production the second year, and is dry farmed for general crop production or is fallow the third year. The more permeable soils are farmed for general crop production each year. Results of land classification surveys show 1,235,000 acres have permeable soils suitable for production of general crops with irrigation. Under future irrigation conditions, it is estimated that, with one-third of the rice type soils irrigated for the production of general crops, a total of 1,965,000 acres of these crops would be irrigated each year. The non-irrigated rice land amounting to 730,000 acres would be dry farmed, as at present.

Present crop distribution and yields were developed from existing records. Future crop distribution was considered to be the same as at present for general crops, and the yields were estimated by using records for the year 1950 when there was no practical deficiency in rainfall and by using records on existing irrigated farms. There is, of course, a good record of rice yields.

On the basis of land use set forth in the preceding paragraph, it is estimated that the irrigation of lands suitable for general crops could increase the crop value by about $22.40 per acre, and the value of crops from lands suitable for rice could be increased by $25.50 per acre. The total area in Arkansas suitable for irrigation (3,425,000 acres) could be expected to produce an increase in the value of crops amounting to $83,550,000 when irrigated. This may be compared with the value of crops reported in the 1950 census of $381,425,000 and is an increase of about 22 percent of that figure. The annual cost of producing this average annual increase in crop value is estimated at 34 percent of the increase or $28,400,000.

An irrigation water supply totally eliminates the hazard of crop loss or failure due to drouth. In unusually dry years the benefits derived from irrigation are much greater than average.

PROBLEMS

The development of irrigation projects in humid areas raises numerous and varied problems. Many, if not all, of the problems to be encountered have been dealt with in the arid and semi-arid regions of the West. In this modern time, with most of the land settled and under cultivation, the problems take a new twist and are not as easily solved as those in the West, where the solutions evolved along with the settlement of the region.

Water Code. - Foremost among the problems to be encountered is an adequate water code. Most of the states in the humid region follow the Riparian

Doctrine which gives a right to use water only to the owners of land adjacent to streams. This doctrine does not adequately recognize beneficial consumptive use of water and depletions of streamflow created thereby. Most of the western states recognize such depletions through the doctrine of appropriation whereby the first in time is the first in right as between appropriators. This latter doctrine establishes a well defined legal right to use water consumptively. Obviously, an investor in a project to divert and use water for irrigation purposes would require some reasonable assurance that the right to use the water is perpetual and not subject to encroachment by subsequent appropriators. It is doubtful that extensive irrigation development can take place in any of the humid areas until an adequate water code is adopted.

Irrigation Practices. - Irrigation practices in humid regions present a problem that will require many years and a great deal of education for solution. In arid regions, the farmer has rapidly learned that he cannot depend on the heavens for his water supply. Crops are irrigated before the wilting point is reached without regard to weather reports or forecasts of rainfall. The farmer in humid areas, exclusive of the rice producer, is inclined to avoid irrigation at every opportunity because it is a comparatively expensive operation both in the expenditure of physical energy and money. It is not uncommon for heavy rainfall to occur during any of the three dry months. If such a rain should occur during or immediately after an irrigation it would appear that the farmer had been premature and had needlessly expended money and energy. If, on the other hand, the rainfall did not occur, the farmer would have wisely expended such energy and money. In the northwestern part of Arkansas, there has been a fairly rapid development of sprinkler irrigation during the last two dry years of 1952 and 1953.

Drainage. - The need for drainage in connection with irrigation developments in humid regions is at least as great as is the need in the arid regions. This need stems from a different cause and requires a treatment which differs from the established practices in the West. As shown in the preceding paragraphs, heavy rains may fall during or immediately after an irrigation. This additional water will largely be refused by the previously saturated soils and will run off. The coincidence of runoff from rainfall with the normal waste from irrigation could easily result in a greater discharge than the natural waterways would be capable of carrying; hence, improved surface water drains are a "must" for full control of irrigation water. In most cases this drainage work will be adequate to control irrigation waste under all but the most adverse conditions.

If surface waste water is adequately controlled, the need for subsurface drainage in Arkansas would be the exception rather than the rule. The soils are usually free of harmful salts and the available surface water is usually equally free of salts. There may be areas requiring special treatment, such as the rolling uplands region where the fairly permeable, shallow soils can accept water at a relatively high rate. The high rate of acceptance of water combined with the steep slope of the ground surface leads to the conclusion that water may accumulate in the valleys more rapidly than the soils can release it to the surface drains, and consequently these valleys may become water logged.

Water Supply. - Nearly all of the present irrigation in Arkansas is by pumping groundwater. Where groundwater supplies may be reached at shallow depths, between 100 and 300 feet with a pumping head of from 50 to 100 feet, it has been found that this is the most economical method of obtaining an

irrigation water supply. As is frequently the case, groundwater resources have been exploited to the extent that the withdrawal of water greatly exceeds the recharge. Overdevelopment of this resource has shown that groundwater is not limitless, and it is causing far-sighted people of the state to look for other sources of water. Although other states of the humid region may have large groundwater supplies, engineers should be constantly aware of the ease and rapidity with which groundwater withdrawals may be overdeveloped. Except in a very few cases, groundwater is not a dependable and permanent source of irrigation water.

Surface water supplies in the humid regions are generally far greater than any conceivable requirement for irrigation. The heavy rainfall on the mountains produces much more runoff than is commonly experienced in the arid and semi-arid regions. The mountainous regions shown in plate 3 yield heavily, and the lower valley areas are suitably located to utilize the runoff. Table 2 shows a comparison of some of the major streams of the United States as compiled from published data of the United States Geological Survey.[4]

The flows of the western streams shown in Table 2 are the residual flows after irrigation depletions. Even though the annual discharge of streams in Arkansas is more than adequate to meet possible irrigation requirements, studies in Arkansas show that storage reservoirs would be necessary to regulate the flows to meet peak diversion demands.

The quality of water for irrigation purposes should not be a serious problem in Arkansas because the soils are generally free of harmful salts and the few samples of water which have been analyzed do not contain alarming quantities.

Conflicting Water Uses. - Past water resource development in humid areas has only partially recognized the use of water for irrigation. Established uses of water will in many cases be in conflict with irrigation use; and in these cases, a great deal of study may be required to determine ways to prevent or mitigate losses to prior use. Some of the existing uses of water are: municipal and industrial, pollution abatement, preservation of fish and wildlife resources, hydroelectric power, and navigation.

Municipal and industrial uses of water require relatively small quantities when compared with irrigation. The law controlling the use of water in most states recognizes this use to be preferred over any other use; however, Arkansas law does not establish priorities between uses. The most likely conflict between irrigation and municipal and industrial water use wil occur when there is a heavy drain on a common groundwater supply. There may be rare cases when surface water supplies would be excessively depleted by irrigation to the detriment of the preferred use. In these latter cases, provision for storing high flows for later use may be the solution to the problem.

Pollution abatement by maintaining adequate flows to dilute sewage and other polluting wastes is a common practice in humid regions. In most cases the minimum natural flows of streams are sufficient to provide the necessary diluting effect. Heavy withdrawals of water for irrigation may reduce the minimum flows so that sewage and other wastes will not be adequately diluted. This problem may be overcome by providing secondary sewage treatment or by providing adequate storage so that irrigation diversions will not deplete the minimum natural flows.

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4. U.S.G.S. Circular 44.

Fish and wildlife resources have been highly developed in some portions of Arkansas, with a substantial income being derived from commercial fishing, sports fishing, and hunting. Depletions of minimum natural flows may cause serious damage to proved fisheries. Development of new lands by clearing timber and brush areas may cause a loss to wildlife resources. In irrigation planning, the engineer should consider these potential losses and the means of mitigating such losses. Stream flows can usually be suitably regulated by storage. Some wildlife losses, particularly those to migratory waterfowl, may be partially mitigated by ponding water in rice fields and other areas during the non-irrigation season.

Hydroelectric power generation is a use of water which is not always incompatible with its use for irrigation. In many cases, the regulation of stream flows provided by power releases will increase the minimum natural flow so that irrigation water may be diverted with little or no loss to other uses described in preceding paragraphs. Existing dams and reservoirs used for the generation of electric power are frequently operated to meet peak energy demands, and a slight modification in the operation of one or two plants in a system may provide necessary irrigation storage with only a very small loss to the system. Associated with the use of water to generate electricity is the need for energy to pump irrigation water when gravity diversions are not economical. Pumping loads are not particularly desirable from the public utility viewpoint because of the low load factor. Peak demands for irrigation water generally exceed the normal flows of streams as modified by releases for power generation to supply commercial loads. Present and future installed generating capacity in the White river system of Arkansas will amount to over one million kilowatts; whereas, the estimated requirement for power for pumping is about two hundred thousand kilowatts. Future investigations should consider the hydrologic integration of the White river system to coordinate water releases for power with water diversion and power requirements for irrigation.

Navigation facilities using the natural stream channels generally require large quantities of water. Basically, the stream channels must have adequate carrying capacity to accommodate large floods. To permit navigation, the minimum water depth in these channels must be maintained at six feet and preferably should be maintained at nine feet. The channel capacity required for floods makes it necessary to discharge large quantities of water to meet minimum depth requirements. In some areas, streams have been improved for navigation; but the low volume of traffic has not warranted the maintenance of structures and the use of these streams has been virtually abandoned. Where it is necessary to maintain navigation facilities, the water thus used will serve the dual purposes of providing fisheries and abating pollution. Water diversions for irrigation may deplete the streamflows so that storage will be required to mitigate damages to navigation.

Construction Problems. - Results of reconnaissance investigations in Arkansas indicate that construction problems would not be new but would be variations of those previously solved elsewhere. Plate 2 shows the lands suitable for irrigation in Arkansas, along with a general plan for serving them. The constructed and potential reservoirs shown on the map have a total ultimate capacity of nearly 34 million acre-feet, and none of this capacity has been allocated to irrigation. A comprehensive study of the storage potentials, with the present allocated uses, may indicate that a reallocation of the capacity to provide for irrigation would be feasible and desirable. The

plan shown in plate 2 will undoubtedly require modification in some respects as additional investigations are completed.

Due to the low gradient of most streams in this area, diversion by gravity would be expensive and difficult, particularly where streams carry large flood flows. Most diversions would be by pumping, and there would be a need for protecting pumping plants from damage by excessive floods. Pumping plant locations which have been investigated vary in size from one plant in northwestern Arkansas with 700 cubic feet per second capacity and a maximum 350 foot head to a small plant along the White river with 20 cubic feet per second capacity and 45 feet of operating head.

CONCLUSIONS

1. Even though the average annual rainfall of Arkansas exceeds the average annual consumptive use, its distribution is such that drouth periods occur every year. There is a need for an irrigation water supply for both rice and general crops in order to fully meet the requirements.

2. A full water supply would increase the average annual crop production and would increase the production in years of extreme drouth so that it would equal or exceed the past production in wet years.

3. Problems in development which may be encountered, although complex, are not fundamentally different from those which have been solved elsewhere. More specifically, problems which need solution are: (a) adoption of an adequate water code; (b) water users' education in irrigation practices; (c) planning and designing adequate drainage systems by full integration with existing systems; (d) development of dependable and permanent water supplies; (e) resolution of conflicting water uses such as municipal and industrial, pollution abatement, fish and wildlife, hydroelectric power, and navigation; and (f) the formulating of a plan for construction which would assure the best use of water through construction by individual or group enterprises, financed with private capital or with federal assistance.

4. A long range program of investigations would be required to develop plans to best utilize the water resources of Arkansas for irrigation and other uses.

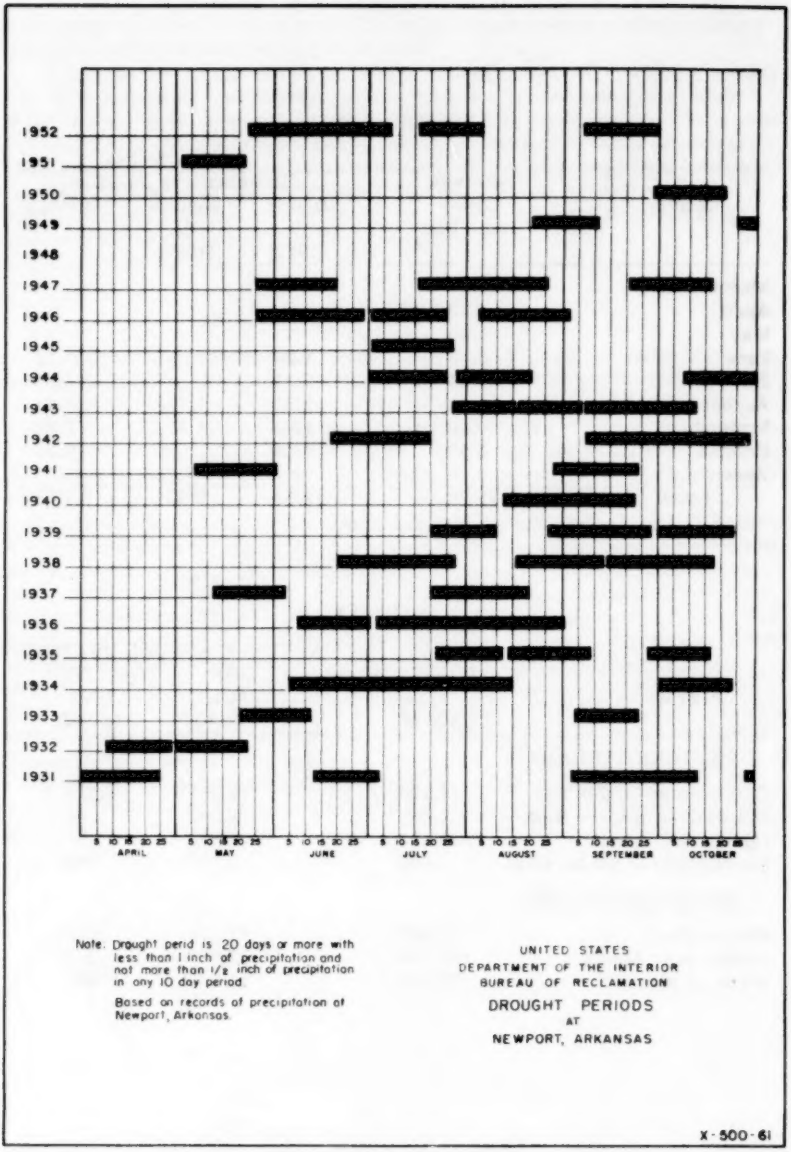
TABLE 1

Units - Inches

Month	Average Gross Cons. Use	Deficiency in Moisture		
		Driest Yr. (1952)	Wettest Yr. (1951)	Average
March	1.44			
April	2.28			
May	4.20			
June	5.52	1.32		0.12
July	6.24	5.04		1.56
August	6.12	2.52	1.20	3.24
September	4.80	1.80	1.20	2.40
October	2.40	1.44		0.36
November	0.96			
Total	33.96	12.12	2.40	7.68

TABLE 2

RIVER	DRAINAGE AREA SQ. MI.	AVERAGE ANNUAL DISCHARGE 1000 ACRE FEET	AC. FT. PER SQ. MI.
WESTERN STREAMS			
Columbia at Coulee Dam	74,100	75,100	1,013
Colorado at Hoover Dam	137,800	13,100	94
Missouri at Mouth	529,400	50,800	96
Sacramento at Shasta Dam	6,600	5,200	788
ARKANSAS STREAMS			
Red at Mouth	91,400	41,500	454
Arkansas at Mouth	160,500	32,700	204
White at Mouth	28,000	22,500	802


1952
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1932
1931
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
Note: Drought perid is 20 days or more with less than 1 inch of precipitation and not more than 1/2 inch of precipitation in any 10 day period.
Based on records of precipitation at Newport, Arkansas.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DROUGHT PERIODS
AT
NEWPORT, ARKANSAS
X-500-61

Figure 1

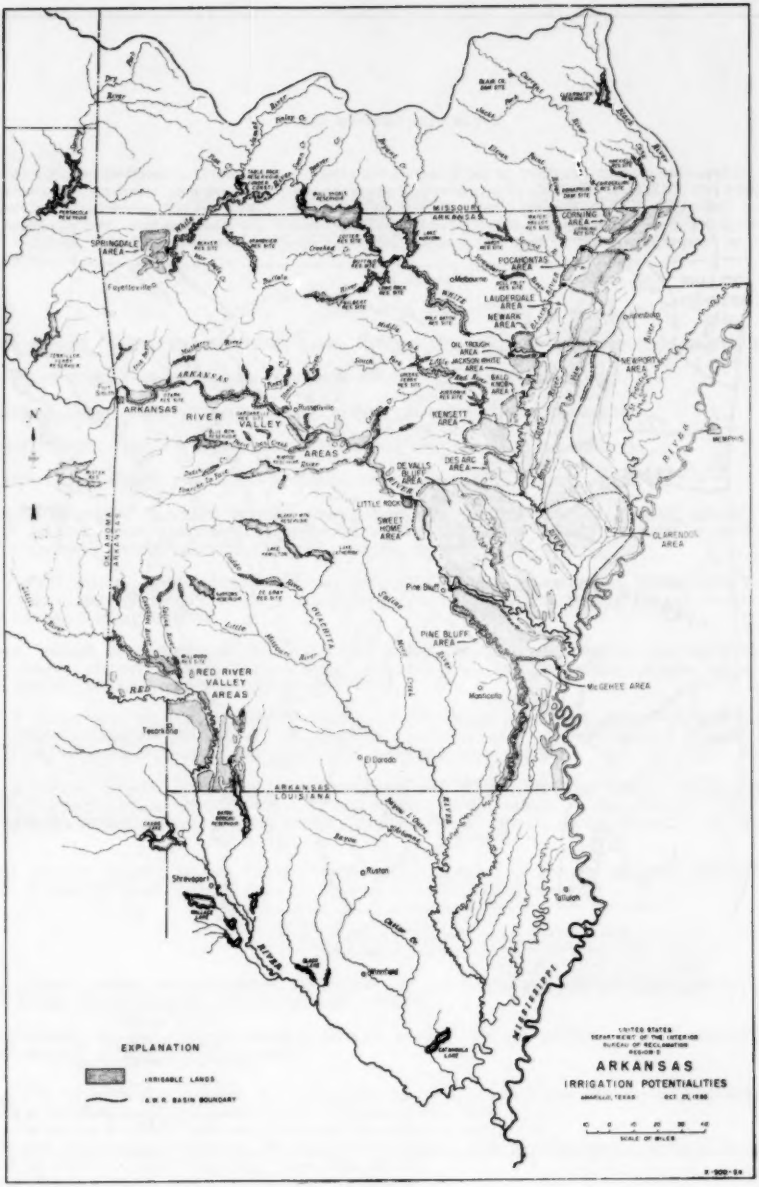
EXPLANATION
IRRIGABLE LANDS
A.W.R. BASIN BOUNDARY
ARKANSAS
IRRIGATION POTENTIALITIES
SPRINGDALE AREA
CONWAY AREA
POCAHONTAS AREA
LAUDERDALE AREA
NEWARK AREA
KENGETT AREA
DES ARC AREA
SWEET HOME AREA
PINE BLUFF AREA
McGEHEE AREA
CLARENDON AREA
RED RIVER VALLEY AREAS
ARKANSAS RIVER VALLEY AREAS
LITTLE ROCK
Fayetteville
Pine Bluff
Texarkana
El Dorado
Ruston
Monroe
Shreveport
Minden
Tallulah
Memphis
Melbourne
Clarendon
Mississippi River
Red River
Ouachita River
Arkansas River
White River
Bayou Macon
Bayou D'Arbonne
Lake Chicot
Lake Enterprise
Lake Providence
Lake Bruin
Lake St. John
Lake Concordia
Lake Catahoula
Lake Bistineau
Lake Claiborne
Lake Dardanelle
Lake Ouachita
Lake Hamilton
Lake Norfork
Lake Greeson
Lake Nimrod
Lake Maumelle
Lake Conway
Lake Beaver
Lake Fayetteville
Lake Wedington
Lake Sequoyah
Lake Fort Smith
Lake Poinsett
Lake Chicot
Lake Village
Lake Enterprise
Lake Providence
Lake Bruin
Lake St. John
Lake Concordia
Lake Catahoula
Lake Bistineau
Lake Claiborne
Lake Dardanelle
Lake Ouachita
Lake Hamilton
Lake Norfork
Lake Greeson
Lake Nimrod
Lake Maumelle
Lake Conway
Lake Beaver
Lake Fayetteville
Lake Wedington
Lake Sequoyah
Lake Fort Smith
Lake Poinsett

Plate 2

ROLLING UPLANDS
OZARK MOUNTAINS
ARKANSAS RIVER VALLEY
OUACHITA MOUNTAINS
RED RIVER VALLEY
OLD COASTAL PLAIN
DELTA
MISSISSIPPI RIVER
MEMPHIS
ARKANSAS
IRRIGATION OPPORTUNITIES
SCALE OF MILES

Plate 3

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The technical papers published in the past twelve months are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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FEBRUARY: 169(HY), 170(ST), 171(CP), 172(SU) & (AT), 173(SU) & (AT), 174(SU) & (AT), 175(HY), D-121(HW), D-127(ST).

MARCH: 176(SA), 177(EM), 178(HY), 179(EM), 180(HY), D-123(HY), D-126(ST), D-128(ST).

APRIL: 181(WW), 182(ST), 184(HY), 185(EM), 186(HY), 187(ST), 188(HY), D-135(HY), D-136(ST).

MAY: 189(HY), 190(HY), 191(CP) & (AT), 192(SM), 193(HY), D-129(PO), D-138(CP), D-145(ST).

JUNE: 194(CP) & (AT), 195(SM), 196(CP) & (AT), 197(HY), 198(ST), 199(EM), D-134(HY), D-141(HY).

JULY: [a] 200(SM)[b], 201(ST)[b], 202(EM)[b], 203(SM)[b], 204(AT)[b], 205(EM)[b], 206(ST)[b], 207(SA)[b], 208(SA)[b], 209(ST)[b], 210(SU)[b], 211(EM)[b], 212(SU)[b], 213(IR)[b], 214(HW)[b], 215(SM)[b], 216(ST)[b], 217(ST)[b], 218(ST)[b], 219(ST)[b], 220(SM)[b], 221(HW)[b], 222(SM)[b], 223(EM)[b], 224(EM)[b], 225(EM)[b], 226(CO)[b], 227(SM)[b], 228(SM)[b], 229(IR)[b].

AUGUST: 230(HY), 231(SA), 232(SA), 233(AT), 234(HW), 235(HW), 237(AT), 238(WW), 239(SA), 240(IR), 241(AT), 242(IR), 243(ST), 244(ST), 245(ST), 246(ST), 247(SA), 248(SA), 249(ST), 250(EM)[c], 251(ST), 252(SA), 253(AT), 254(HY), 255(AT), 256(ST), 257(SA), 258(EM), 259(WW).

SEPTEMBER: 260(AT), 261(EM), 262(SM), 263(ST), 264(WW), 265(ST), 266(ST), 267(SA), 268(CO), 269(CO), 270(CO), 271(SU), 272(SA), 273(PO), 274(HY), 275(WW), 276(HW), 277(SU), 278(SU), 279(SA), 280(IR), 281(EM), 282(SU), 283(SA), 284(SU), 285(CP), 286(EM), 287(EM), 288(SA), 289(CO).

OCTOBER: [d] 290(all Divs), 291(ST)[c], 292(EM)[c], 293(ST)[c], 294(PO)[c], 295(HY)[c], 296(EM)[c], 297(HY)[c], 298(ST)[c], 299(EM)[c], 300(EM)[c], 301(SA)[c], 302(SA)[c], 303(SA)[c], 304(CO)[c], 305(SU)[c], 306(ST)[c], 307(SA)[c], 308(PO)[c], 309(SA)[c], 310(SA)[c], 311(SM)[c], 312(SA)[c], 313(ST)[c], 314(SA)[c], 315(SM)[c], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

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DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[e], 368(WW)[e], 369(IR), 370(AT)[e], 371(SM)[e], 372(CO)[e], 373(ST)[e], 374(EM)[e], 375(EM), 376(EM), 377(SA)[e], 378(PO)[e].

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e. Discussion of several papers, grouped by divisions.
f. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.

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FEBRUARY, 1954

IRRIGATION POTENTIALITIES IN ARKANSAS

by Paul H. Berg, A.M. ASCE

Presented at
Atlanta Convention
February 15-19, 1954

IRRIGATION AND DRAINAGE
DIVISION

{Discussion open until June 1, 1954}

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IRRIGATION POTENTIALITIES IN ARKANSAS

Paul H. Berg,[1] A.M. ASCE

SYNOPSIS

The rainfall in Arkansas, although abundant when measured annually, is insufficient to meet the crop requirements during the growing season. Irrigation to supplement the growing season rainfall deficiency would result in an increased production of crops. This paper discusses some of the problems which may be encountered with the development of irrigation in Arkansas.

INTRODUCTION

In 1950 the population of the United States was approximately 150 million. It is conservatively estimated that by 1975 this population will have increased to 190 million; and by the year 2000, the population will total 215 million. This increase in population will cause an ever increasing demand for food and fiber. Reduced to simpler terms this means that, for every four people that are fed in the nation today, five will have to be fed by 1975, and six will have to be fed by 2000. In addition to the increasing need due to increasing population, it is anticipated that the dietary standards of the people of the nation will continue to improve in future years as in the past.

In past decades the increasing need for production has been met by (1) new farmland brought under cultivation, (2) conversion of land from production of feed for draft animals, (3) increased use of fertilizer, (4) improved farming methods, (5) improved varieties of crops, (6) elimination of drouth by irrigation, and (7) importation from other countries. Further increases in production by the first two methods will be extremely limited. This paper deals with only one of the remaining items--elimination of drouth by irrigation.

The information contained in this paper was largely obtained and compiled as a result of a study of the problem in the State of Arkansas by the Bureau of Reclamation. The investigation was a part of the work carried on under the Flood Control Act of 1950 for a cooperative inter-agency investigation of the Arkansas, White, and Red River basins. Arkansas lies wholly within the humid region of the United States and there is every reason to believe the results of this investigation are typical of those which might be obtained in other humid areas. Every effort was made to determine (1) the need for additional water to supplement natural precipitation in this humid region, (2) the probable increase in crop value which could be expected, and (3) the construction and other problems which may be encountered in development of potentially irrigable areas. Plate 3 shows the areas in Arkansas which were studied.

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1. AWR Basins Planning Engineer, Bureau of Reclamation, Tulsa, Oklahoma.

Need for Additional Water

In general, the need for irrigation is indicated by (1) the deficiency in natural precipitation required to provide the water consumptively used by crops and (2) the increase in crop production which will result from supplying this deficiency by irrigation. These subjects have received comparatively little study in the humid regions because the economic pressures for maximum crop production have not yet been great either locally or nationally.

The climate of Arkansas is quite similar to that of other southern states. Summers are long and warm with temperatures occasionally going above 100 degrees and with the humidity staying at about 70 percent. Winters are mild with temperatures rarely going below zero. The average annual rainfall approaches 50 inches and varies from a minimum of 24 inches to a maximum of 84 inches. Unlike the semi-arid regions of the West, about 70 percent of the rainfall occurs during the winter and spring months; consequently, the summer or growing season precipitation does not differ materially from that of the semi-arid regions. The average growing season is quite long, being 247 days at Fayetteville in the northwestern part of Arkansas, 274 days at Newport in the east-central part, and 308 days at Portland in the southwestern part. The growing season generally starts in the first half of March and ends in the last half of November.

In the studies which were made in Arkansas, one comparatively specialized problem arose in connection with the determination of the need for water for rice production. Rice can only be grown in standing water with a controlled depth of from 4 to 7 inches. Water is applied to the rice fields at the beginning of the season; it is later drained off, and the fields are allowed to dry out for about two weeks. Water is then reapplied and maintained at the above mentioned depth for the remainder of the growing period. The need is thereby based upon factors other than the consumptive use of the plants. A quantative evaluation of the need was made from studies of pumping records where pumps were used as the sole source of irrigation water for relatively large areas of rice cultivation over long periods of time.

In the case of general crops as grown in Arkansas and elsewhere throughout the nation, the need for water is based upon the consumptive use of the particular crops in question. It has long been recognized that throughout the entire nation crop production is frequently restricted by the failure of rains to fall in the proper amounts at the proper time. This is particularly true in Arkansas where there are frequent periods of apparent drouth, with one or more short periods occurring each year. A drouth period is defined as any period of 20 days or longer each 10 days of which has less than one-half inch of rainfall.

Figure 1 shows the apparent drouths which have occurred at Newport, Arkansas, from 1931 to 1952, inclusive.

As a first step in the determination of the need for additional water, it is necessary to determine what amount and distribution of water the various crops need for optimum production. It is then necessary to determine what portion of that requirement is supplied by precipitation. The remainder, if any, is the requirement for additional water. Consumptive use and effective precipitation studies were made, using climatological data from stations at Fayetteville, Newport, and Portland, Arkansas. These studies led to a determination of the deficiency in rainfall required to meet consumptive use requirements. Annual gross consumptive use of water was estimated by the

Lowry-Johnson method,[2] and it was found to average 31.8 inches in the northwestern portion of the state, 34.9 inches in the east-central portion, and 37.2 inches in the southeastern portion. The annual consumptive use was distributed by months according to monthly effective heat and was adjusted to meet the probable cropping pattern. Effective precipitation studies were made using climatological data from the same stations that were selected for the preparation of consumptive use studies. Experience has demonstrated that not all precipitation which falls during the growing season is effective in meeting the consumptive use requirements of crops. It has further been found that as rainfall increases, the percentage of that rainfall which is effective in meeting consumptive use requirements decreases. On the basis of experience in other areas, a curve was developed for estimating the monthly effective precipitation from the recorded actual precipitation. Effective precipitation was deducted from the monthly gross consumptive use to determine the deficiency in moisture. When the effective precipitation exceeded the consumptive use, the excess was considered to accumulate month to month so long as the accumulated carry over did not exceed the estimated optimum soil moisture capacity. Table 1 shows the monthly distribution of the average gross consumptive use at Newport, Arkansas, and the deficiency in moisture for the growing season months of March through November for a dry year (1952), a wet year (1951), and the twenty-two year average (1931 to 1952, inclusive).

Many of the apparent drouth periods shown in Figure 1 occur in May and June, whereas Table 1 shows very little deficiency in moisture for these months. This is readily explained by the fact that effective precipitation during previous months has exceeded the consumptive use and there has been a substantial carry over of soil moisture. A careful review of Table 1 leads to the conclusion that the dry year of 1952 had water deficiency characteristics somewhat different from the average. Water deficiency may be expected in August and September of every year, whereas, such deficiencies do not always occur in July. The soil moisture carry over from June frequently sustains crops through a July drouth. The results of the consumptive use and effective precipitation studies show that some additional water is required every year to meet the full crop requirement.

Increase in Crop Value

Experience in Arkansas since 1904 has shown that the production of rice will yield greater income per acre than will any other crop now grown in quantity in that state. Rice can be grown only with irrigation. In 1950 rice was harvested from 411,000 acres of the approximately 1,386,000 acres in irrigated farms.[3] The reconnaissance land classification by the Bureau of Reclamation shows 2,190,000 acres suitable for rice production. Of this acreage, about one-third, or 730,000 acres, could produce rice each year. This is an increase of 78 percent over the acreage harvested in 1950. It is commonly recognized that there would be an increase in income by the irrigation of more rice; provided, the nation as a whole will consume the increased rice production. A study of rice production in the United States and a forecast of future demand for rice was completed in 1953. This study indicates that a

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2. A.S.C.E. Transactions, Vol. 107. 1942, Page 1243
3. U. S. Census

total of 2,109,000 acres of rice should be harvested in the United States in the year 2010 in order to meet the estimated national requirement of 106,600,000 bushels. The development of most of the rice type land in Arkansas currently unused, as well as efficient use of the land resources in the other rice producing states, would be necessary to meet the forecast requirements. These production requirements exclude the effect of even partial achievement of the Rice Millers' goal of stimulating civilian domestic rice consumption above 5.5 pounds per capita. Any significant success in stimulating domestic use would, under normal trend conditions, utilize all the land of the Nation suited to rice production and decreasing quantities would be available for export.

Irrigation is not generally practiced to raise crops such as cotton, corn, oats, lespedeza, and soybeans; nor is it practiced in the northwestern part of the state where grapes, fruits, and fresh vegetables are raised. Land that is suitable for rice cultivation is used for rice one year, is irrigated (when water is available) for general crop production the second year, and is dry farmed for general crop production or is fallow the third year. The more permeable soils are farmed for general crop production each year. Results of land classification surveys show 1,235,000 acres have permeable soils suitable for production of general crops with irrigation. Under future irrigation conditions, it is estimated that, with one-third of the rice type soils irrigated for the production of general crops, a total of 1,965,000 acres of these crops would be irrigated each year. The non-irrigated rice land amounting to 730,000 acres would be dry farmed, as at present.

Present crop distribution and yields were developed from existing records. Future crop distribution was considered to be the same as at present for general crops, and the yields were estimated by using records for the year 1950 when there was no practical deficiency in rainfall and by using records on existing irrigated farms. There is, of course, a good record of rice yields.

On the basis of land use set forth in the preceding paragraph, it is estimated that the irrigation of lands suitable for general crops could increase the crop value by about $22.40 per acre, and the value of crops from lands suitable for rice could be increased by $25.50 per acre. The total area in Arkansas suitable for irrigation (3,425,000 acres) could be expected to produce an increase in the value of crops amounting to $83,550,000 when irrigated. This may be compared with the value of crops reported in the 1950 census of $381,425,000 and is an increase of about 22 percent of that figure. The annual cost of producing this average annual increase in crop value is estimated at 34 percent of the increase or $28,400,000.

An irrigation water supply totally eliminates the hazard of crop loss or failure due to drouth. In unusually dry years the benefits derived from irrigation are much greater than average.

PROBLEMS

The development of irrigation projects in humid areas raises numerous and varied problems. Many, if not all, of the problems to be encountered have been dealt with in the arid and semi-arid regions of the West. In this modern time, with most of the land settled and under cultivation, the problems take a new twist and are not as easily solved as those in the West, where the solutions evolved along with the settlement of the region.

Water Code. - Foremost among the problems to be encountered is an adequate water code. Most of the states in the humid region follow the Riparian

Doctrine which gives a right to use water only to the owners of land adjacent to streams. This doctrine does not adequately recognize beneficial consumptive use of water and depletions of streamflow created thereby. Most of the western states recognize such depletions through the doctrine of appropriation whereby the first in time is the first in right as between appropriators. This latter doctrine establishes a well defined legal right to use water consumptively. Obviously, an investor in a project to divert and use water for irrigation purposes would require some reasonable assurance that the right to use the water is perpetual and not subject to encroachment by subsequent appropriators. It is doubtful that extensive irrigation development can take place in any of the humid areas until an adequate water code is adopted.

Irrigation Practices. - Irrigation practices in humid regions present a problem that will require many years and a great deal of education for solution. In arid regions, the farmer has rapidly learned that he cannot depend on the heavens for his water supply. Crops are irrigated before the wilting point is reached without regard to weather reports or forecasts of rainfall. The farmer in humid areas, exclusive of the rice producer, is inclined to avoid irrigation at every opportunity because it is a comparatively expensive operation both in the expenditure of physical energy and money. It is not uncommon for heavy rainfall to occur during any of the three dry months. If such a rain should occur during or immediately after an irrigation it would appear that the farmer had been premature and had needlessly expended money and energy. If, on the other hand, the rainfall did not occur, the farmer would have wisely expended such energy and money. In the northwestern part of Arkansas, there has been a fairly rapid development of sprinkler irrigation during the last two dry years of 1952 and 1953.

Drainage. - The need for drainage in connection with irrigation developments in humid regions is at least as great as is the need in the arid regions. This need stems from a different cause and requires a treatment which differs from the established practices in the West. As shown in the preceding paragraphs, heavy rains may fall during or immediately after an irrigation. This additional water will largely be refused by the previously saturated soils and will run off. The coincidence of runoff from rainfall with the normal waste from irrigation could easily result in a greater discharge than the natural waterways would be capable of carrying; hence, improved surface water drains are a "must" for full control of irrigation water. In most cases this drainage work will be adequate to control irrigation waste under all but the most adverse conditions.

If surface waste water is adequately controlled, the need for subsurface drainage in Arkansas would be the exception rather than the rule. The soils are usually free of harmful salts and the available surface water is usually equally free of salts. There may be areas requiring special treatment, such as the rolling uplands region where the fairly permeable, shallow soils can accept water at a relatively high rate. The high rate of acceptance of water combined with the steep slope of the ground surface leads to the conclusion that water may accumulate in the valleys more rapidly than the soils can release it to the surface drains, and consequently these valleys may become water logged.

Water Supply. - Nearly all of the present irrigation in Arkansas is by pumping groundwater. Where groundwater supplies may be reached at shallow depths, between 100 and 300 feet with a pumping head of from 50 to 100 feet, it has been found that this is the most economical method of obtaining an

irrigation water supply. As is frequently the case, groundwater resources have been exploited to the extent that the withdrawal of water greatly exceeds the recharge. Overdevelopment of this resource has shown that groundwater is not limitless, and it is causing far-sighted people of the state to look for other sources of water. Although other states of the humid region may have large groundwater supplies, engineers should be constantly aware of the ease and rapidity with which groundwater withdrawals may be overdeveloped. Except in a very few cases, groundwater is not a dependable and permanent source of irrigation water.

Surface water supplies in the humid regions are generally far greater than any conceivable requirement for irrigation. The heavy rainfall on the mountains produces much more runoff than is commonly experienced in the arid and semi-arid regions. The mountainous regions shown in plate 3 yield heavily, and the lower valley areas are suitably located to utilize the runoff. Table 2 shows a comparison of some of the major streams of the United States as compiled from published data of the United States Geological Survey.[4]

The flows of the western streams shown in Table 2 are the residual flows after irrigation depletions. Even though the annual discharge of streams in Arkansas is more than adequate to meet possible irrigation requirements, studies in Arkansas show that storage reservoirs would be necessary to regulate the flows to meet peak diversion demands.

The quality of water for irrigation purposes should not be a serious problem in Arkansas because the soils are generally free of harmful salts and the few samples of water which have been analyzed do not contain alarming quantities.

Conflicting Water Uses. - Past water resource development in humid areas has only partially recognized the use of water for irrigation. Established uses of water will in many cases be in conflict with irrigation use; and in these cases, a great deal of study may be required to determine ways to prevent or mitigate losses to prior use. Some of the existing uses of water are: municipal and industrial, pollution abatement, preservation of fish and wildlife resources, hydroelectric power, and navigation.

Municipal and industrial uses of water require relatively small quantities when compared with irrigation. The law controlling the use of water in most states recognizes this use to be preferred over any other use; however, Arkansas law does not establish priorities between uses. The most likely conflict between irrigation and municipal and industrial water use wil occur when there is a heavy drain on a common groundwater supply. There may be rare cases when surface water supplies would be excessively depleted by irrigation to the detriment of the preferred use. In these latter cases, provision for storing high flows for later use may be the solution to the problem.

Pollution abatement by maintaining adequate flows to dilute sewage and other polluting wastes is a common practice in humid regions. In most cases the minimum natural flows of streams are sufficient to provide the necessary diluting effect. Heavy withdrawals of water for irrigation may reduce the minimum flows so that sewage and other wastes will not be adequately diluted. This problem may be overcome by providing secondary sewage treatment or by providing adequate storage so that irrigation diversions will not deplete the minimum natural flows.

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4. U.S.G.S. Circular 44.

Fish and wildlife resources have been highly developed in some portions of Arkansas, with a substantial income being derived from commercial fishing, sports fishing, and hunting. Depletions of minimum natural flows may cause serious damage to proved fisheries. Development of new lands by clearing timber and brush areas may cause a loss to wildlife resources. In irrigation planning, the engineer should consider these potential losses and the means of mitigating such losses. Stream flows can usually be suitably regulated by storage. Some wildlife losses, particularly those to migratory waterfowl, may be partially mitigated by ponding water in rice fields and other areas during the non-irrigation season.

Hydroelectric power generation is a use of water which is not always incompatible with its use for irrigation. In many cases, the regulation of stream flows provided by power releases will increase the minimum natural flow so that irrigation water may be diverted with little or no loss to other uses described in preceding paragraphs. Existing dams and reservoirs used for the generation of electric power are frequently operated to meet peak energy demands, and a slight modification in the operation of one or two plants in a system may provide necessary irrigation storage with only a very small loss to the system. Associated with the use of water to generate electricity is the need for energy to pump irrigation water when gravity diversions are not economical. Pumping loads are not particularly desirable from the public utility viewpoint because of the low load factor. Peak demands for irrigation water generally exceed the normal flows of streams as modified by releases for power generation to supply commercial loads. Present and future installed generating capacity in the White river system of Arkansas will amount to over one million kilowatts; whereas, the estimated requirement for power for pumping is about two hundred thousand kilowatts. Future investigations should consider the hydrologic integration of the White river system to coordinate water releases for power with water diversion and power requirements for irrigation.

Navigation facilities using the natural stream channels generally require large quantities of water. Basically, the stream channels must have adequate carrying capacity to accommodate large floods. To permit navigation, the minimum water depth in these channels must be maintained at six feet and preferably should be maintained at nine feet. The channel capacity required for floods makes it necessary to discharge large quantities of water to meet minimum depth requirements. In some areas, streams have been improved for navigation; but the low volume of traffic has not warranted the maintenance of structures and the use of these streams has been virtually abandoned. Where it is necessary to maintain navigation facilities, the water thus used will serve the dual purposes of providing fisheries and abating pollution. Water diversions for irrigation may deplete the streamflows so that storage will be required to mitigate damages to navigation.

Construction Problems. - Results of reconnaissance investigations in Arkansas indicate that construction problems would not be new but would be variations of those previously solved elsewhere. Plate 2 shows the lands suitable for irrigation in Arkansas, along with a general plan for serving them. The constructed and potential reservoirs shown on the map have a total ultimate capacity of nearly 34 million acre-feet, and none of this capacity has been allocated to irrigation. A comprehensive study of the storage potentials, with the present allocated uses, may indicate that a reallocation of the capacity to provide for irrigation would be feasible and desirable. The

plan shown in plate 2 will undoubtedly require modification in some respects as additional investigations are completed.

Due to the low gradient of most streams in this area, diversion by gravity would be expensive and difficult, particularly where streams carry large flood flows. Most diversions would be by pumping, and there would be a need for protecting pumping plants from damage by excessive floods. Pumping plant locations which have been investigated vary in size from one plant in northwestern Arkansas with 700 cubic feet per second capacity and a maximum 350 foot head to a small plant along the White river with 20 cubic feet per second capacity and 45 feet of operating head.

CONCLUSIONS

1. Even though the average annual rainfall of Arkansas exceeds the average annual consumptive use, its distribution is such that drouth periods occur every year. There is a need for an irrigation water supply for both rice and general crops in order to fully meet the requirements.

2. A full water supply would increase the average annual crop production and would increase the production in years of extreme drouth so that it would equal or exceed the past production in wet years.

3. Problems in development which may be encountered, although complex, are not fundamentally different from those which have been solved elsewhere. More specifically, problems which need solution are: (a) adoption of an adequate water code; (b) water users' education in irrigation practices; (c) planning and designing adequate drainage systems by full integration with existing systems; (d) development of dependable and permanent water supplies; (e) resolution of conflicting water uses such as municipal and industrial, pollution abatement, fish and wildlife, hydroelectric power, and navigation; and (f) the formulating of a plan for construction which would assure the best use of water through construction by individual or group enterprises, financed with private capital or with federal assistance.

4. A long range program of investigations would be required to develop plans to best utilize the water resources of Arkansas for irrigation and other uses.

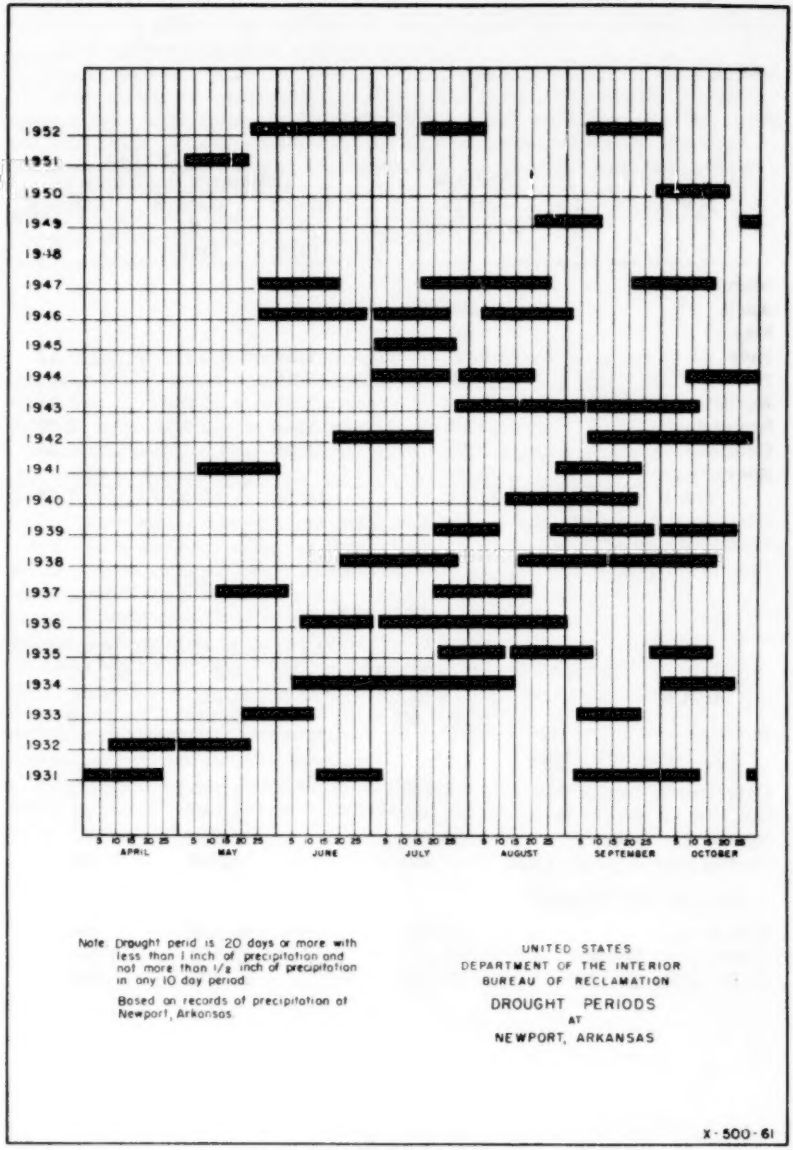
TABLE 1

Units - Inches

Month	Average Gross Cons. Use	Deficiency in Moisture		
		Driest Yr. (1952)	Wettest Yr. (1951)	Average
March	1.44			
April	2.28			
May	4.20			
June	5.52	1.32		0.12
July	6.24	5.04		1.56
August	6.12	2.52	1.20	3.24
September	4.80	1.80	1.20	2.40
October	2.40	1.44		0.36
November	0.96			
Total	33.96	12.12	2.40	7.68

TABLE 2

RIVER	DRAINAGE AREA SQ. MI.	AVERAGE ANNUAL DISCHARGE 1000 ACRE FEET	AC. FT. PER SQ. MI.
WESTERN STREAMS			
Columbia at Coulee Dam	74,100	75,100	1,013
Colorado at Hoover Dam	137,800	13,100	94
Missouri at Mouth	529,400	50,800	96
Sacramento at Shasta Dam	6,600	5,200	788
ARKANSAS STREAMS			
Red at Mouth	91,400	41,500	454
Arkansas at Mouth	160,500	32,700	204
White at Mouth	28,000	22,500	802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1932
1931
5 10 15 20 25
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
Note: Drought perid is 20 days or more with less than 1 inch of precipitation and not more than 1/2 inch of precipitation in any 10 day period.
Based on records of precipitation at Newport, Arkansas.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DROUGHT PERIODS
AT
NEWPORT, ARKANSAS
X-500-61

Figure 1

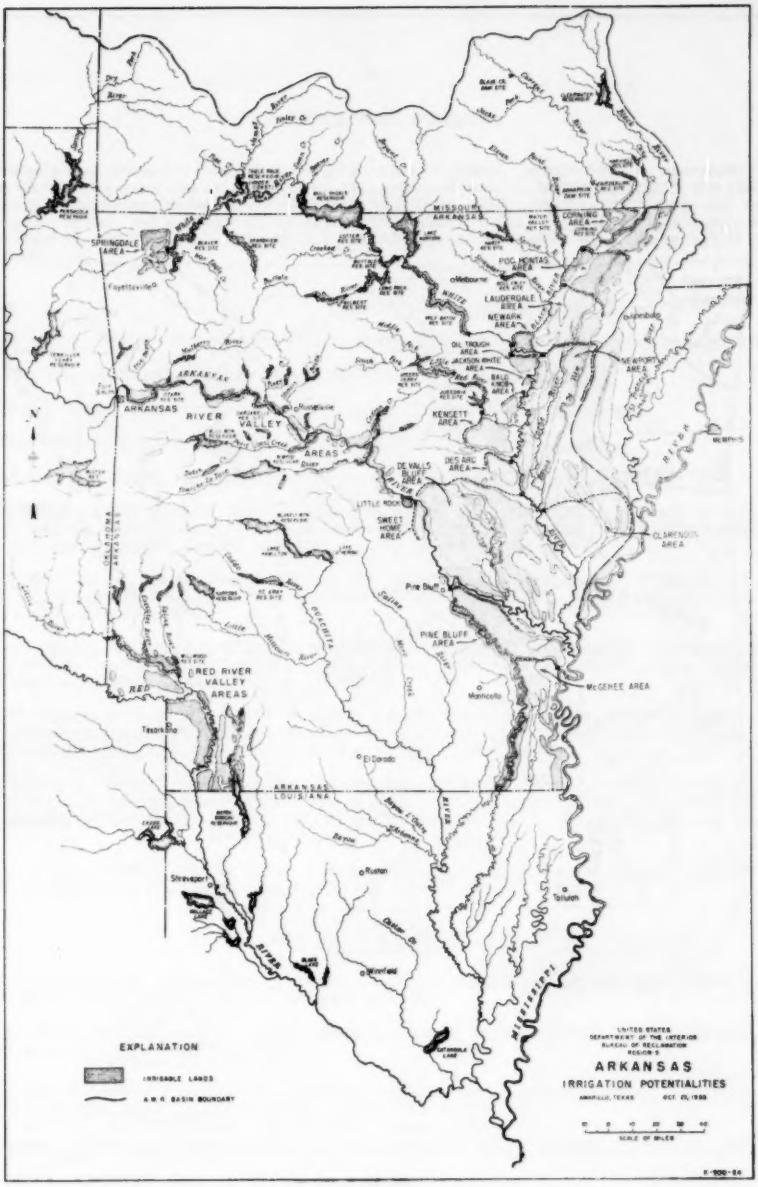
SPRINGDALE AREA
MISSOURI ARKANSAS
CORNING AREA
POCAHONTAS AREA
LAUDERDALE AREA
NEWARK AREA
OIL TROUGH AREA
JACKSON-WHITE AREA
ARKANSAS RIVER VALLEY AREAS
KENSETT AREA
DE VALLS BLUFF AREA
DES ARC AREA
LITTLE ROCK
SWEET HOME AREA
PINE BLUFF AREA
McGEHEE AREA
RED RIVER VALLEY AREAS
ARKANSAS LOUISIANA
EXPLANATION
IRRIGABLE LANDS
A.W.R. BASIN BOUNDARY
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION REGION 5
ARKANSAS
IRRIGATION POTENTIALITIES
AMARILLO, TEXAS OCT. 25, 1950
SCALE OF MILES

Plate 2

ROLLING UPLANDS
OZARK MOUNTAINS
ARKANSAS RIVER VALLEY
OUACHITA MOUNTAINS
RED RIVER VALLEY
OLD COASTAL PLAIN
DELTA
MISSISSIPPI RIVER
MEMPHIS
ARKANSAS
IRRIGATION OPPORTUNITIES
SCALE OF MILES

Plate 3

PROCEEDINGS-SEPARATES

The technical papers published in the past twelve months are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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FEBRUARY: 169(HY), 170(ST), 171(CP), 172(SU) & (AT), 173(SU) & (AT), 174(SU) & (AT), 175(HY), D-121(HW), D-127(ST).

MARCH: 176(SA), 177(EM), 178(HY), 179(EM), 180(HY), D-123(HY), D-126(ST), D-128(ST).

APRIL: 181(WW), 182(ST), 184(HY), 185(EM), 186(HY), 187(ST), 188(HY), D-135(HY), D-136(ST).

MAY: 189(HY), 190(HY), 191(CP) & (AT), 192(SM), 193(HY), D-129(PO), D-138(CP), D-145(ST).

JUNE: 194(CP) & (AT), 195(SM), 196(CP) & (AT), 197(HY), 198(ST), 199(EM), D-134(HY), D-141(HY).

JULY: [a] 200(SM)[b], 201(ST)[b], 202(EM)[b], 203(SM)[b], 204(AT)[b], 205(EM)[b], 206(ST)[b], 207(SA)[b], 208(SA)[b], 209(ST)[b], 210(SU)[b], 211(EM)[b], 212(SU)[b], 213(IR)[b], 214(HW)[b], 215(SM)[b], 216(ST)[b], 217(ST)[b], 218(ST)[b], 219(ST)[b], 220(SM)[b], 221(HW)[b], 222(SM)[b], 223(EM)[b], 224(EM)[b], 225(EM)[b], 226(CO)[b], 227(SM)[b], 228(SM)[b], 229(IR)[b].

AUGUST: 230(HY), 231(SA), 232(SA), 233(AT), 234(HW), 235(HW), 237(AT), 238(WW), 239(SA), 240(IR), 241(AT), 242(IR), 243(ST), 244(ST), 245(ST), 246(ST), 247(SA), 248(SA), 249(ST), 250(EM)[c], 251(ST), 252(SA), 253(AT), 254(HY), 255(AT), 256(ST), 257(SA), 258(EM), 259(WW).

SEPTEMBER: 260(AT), 261(EM), 262(SM), 263(ST), 264(WW), 265(ST), 266(ST), 267(SA), 268(CO), 269(CO), 270(CO), 271(SU), 272(SA), 273(PO), 274(HY), 275(WW), 276(HW), 277(SU), 278(SU), 279(SA), 280(IR), 281(EM), 282(SU), 283(SA), 284(SU), 285(CP), 286(EM), 287(EM), 288(SA), 289(CO).

OCTOBER: [d] 290(all Divs), 291(ST)[c], 292(EM)[c], 293(ST)[c], 294(PO)[c], 295(HY)[c], 296(EM)[c], 297(HY)[c], 298(ST)[c], 299(EM)[c], 300(EM)[c], 301(SA)[c], 302(SA)[c], 303(SA)[c], 304(CO)[c], 305(SU)[c], 306(ST)[c], 307(SA)[c], 308(PO)[c], 309(SA)[c], 310(SA)[c], 311(SM)[c], 312(SA)[c], 313(ST)[c], 314(SA)[c], 315(SM)[c], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

NOVEMBER: 321(ST), 322(ST), 323(SM), 324(SM), 325(SM), 326(SM), 327(SM), 328(SM), 329(HW), 330(EM)[c], 331(EM)[c], 332(EM)[c], 333(EM)[e], 334(EM), 335(SA), 336(SA), 337(SA), 338(SA), 339(SA), 340(SA), 341(SA), 342(CO), 343(ST), 344(ST), 345(ST), 346(IR), 347(IR), 348(CO), 349(SM), 350(HW), 351(HW), 352(SA), 353(SU), 354(HY), 355(PO), 356(CO), 357(HW), 358(HY).

DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[e], 368(WW)[e], 369(IR), 370(AT)[e], 371(SM)[e], 372(CO)[e], 373(ST)[e], 374(EM)[e], 375(EM), 376(EM), 377(SA)[e], 378(PO)[e].

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JANUARY: 379(SM)[e], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[e], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[e], 390(HY), 391(IR)[e], 392(SA), 393(SU), 394(AT), 395(SA)[e], 396(EM)[e], 397(ST)[e].

FEBRUARY: 398(IR)[f], 399(SA)[f], 400(CO)[f], 401(SM)[f], 402(AT)[f], 403(AT)[f], 404(IR)[f], 405(PO)[f], 406(AT)[f], 407(SU)[f], 408(SU)[f], 409(WW)[f], 410(AT)[f], 411(SA)[f], 412(PO)[f], 413(HY)[f].

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a. Beginning with "Proceedings-Separate No. 200," published in July, 1953, the papers were printed by the photo-offset method.
b. Presented at the Miami Beach (Fla.) Convention of the Society in June, 1953.
c. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
d. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
e. Discussion of several papers, grouped by divisions.
f. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.

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